Study Plan: Assessing Ecosystem Services and Carbon Balance in Support of Land Management at the Great Dismal Swamp, Pocosin Lakes, and Alligator River National Wildlife Refuges

Introduction and Objectives:

The greenhouse gases (GHG) including carbon dioxide and methane are well known drivers of climate change. Long term sequestration of sufficient GHG is expected to help mitigate the effects of climate change. Plants biologically convert atmospheric carbon dioxide into plant material where it is sequestered until those materials decompose to form carbon dioxide and methane, which subsequently can rerelease to the atmosphere. The balance between carbon sequestration and release differs among ecosystems with some ecosystems being much more effective at long term sequestration of carbon. By better understanding the factors that control the sequestration and release of carbon in different ecosystems, many ecosystems could potentially be managed to more effectively sequester carbon, and release less carbon, to help mitigate climate change.

The U.S. Geological Survey (USGS) Land Carbon project is a national assessment of biologic carbon sequestration in ecosystems such as forests, grasslands, shrub lands, croplands, wetlands, and aquatic habitats. This assessment estimates baseline and future potential carbon storage and GHG fluxes in different ecosystems (Zhu et al., 2010). A priority of the assessment is to estimate local- and regional-scale carbon fluxes, ecosystem carbon balances, and long term sequestration rates, and include these estimates in ecosystem service evaluations in support of the Department of the Interior land management.

Ecosystem services are the benefits provided by the natural environment that are of value to people such as provisioning services (food and water), regulating services (e.g., climate and flood protection), cultural services (e.g., cultural and recreational benefits), and supporting services (e.g., nutrient cycling). The ability of the natural environment to provide ecosystem services is threatened by development, pollution, fragmentation, resource overuse and climate change. By assessing, quantifying, and valuing ecosystem services, this project may be used to address how services such as biodiversity, recreation (e.g., bird watching), or nutrient cycling among others may be impacted by management activities, including strategies to enhance the service of carbon sequestration.

This study plan describes a collaborative research project to assess ecosystem services and estimate carbon balance in relation to water management and other restoration actions at the Great Dismal Swamp (GDS) National Wildlife Refuge (NWR). Research is also conducted at Pocosin Lakes (PL) and potentially the Alligator River (AR) NWR. Extensive ditch networks drain or otherwise affect the water regimes of the ecosystems at these refuges. Hydrologic manipulation to manage soil water percent saturation is an important method for restoration of the wetland ecosystems and may improve carbon sequestration and other ecosystem services.

The ability for public lands to maximize the ecosystem service of carbon sequestration is a focus of this project. Increasing carbon sequestration addresses a key refuge management objective to restore and enhance the quality and resilience of peat soils. As such, this work explicitly examines carbon storage, sequestration, and GHG fluxes in representative GDS NWR vegetation communities. The integration of carbon sequestration and other ecosystem services in relation to selected land management and restoration actions will allow analysis focused on decision-making on public lands. The ecosystem service evaluation will also help improve the understanding of how that decision-making affects carbon sequestration, carbon storage, and GHG fluxes, as related to natural and anthropogenic processes including land use, water management, fire, and climate change.

The objectives of this collaborative project are to: (1) characterize potential carbon sequestration in representative vegetation communities via gaseous and water based carbon fluxes and via carbon storage in biomass and soil pools; (2) estimate the effects of refuge hydrologic management and restoration on carbon sequestration, fire management, and establishing selected types of resilient vegetation communities; and (3) provide an assessment and valuation of selected ecosystem services potentially including carbon sequestration, biodiversity, recreation (e.g., bird watching), or nutrient cycling. The results of the study will inform refuge staff on how hydrologic management affects carbon storage and what approaches may be used to restore selected vegetation community habitats and improve ecosystem services.

Scope and Relationship between Study Components:

The study areas include GDS and PL; however, the initial focus will primarily be on the GDS. Figure 1 outlines the relationship between project components for GDS. At GDS, the study will be conducted at local scale study sites where we will measure carbon storage and fluxes in soils and groundwater, water table levels, biomass, and soil moisture in three representative vegetation communities. Our goal is to scale up those measurements to swamp and regional scales using remote sensing methods. The field carbon research also will be used in the ecosystem services assessment for decision support and incorporation of management and stakeholder needs. This study will be conducted collaboratively by a team of scientists, technical staff, managers, and students from the U.S. Geological Survey (USGS), the U.S. Fish and Wildlife Service (FWS), the Nature Conservancy (TNC), and universities including George Mason University, Southern Methodist University, and Clemson University. (Please see Appendix F for organizations, participants, and a draft project coordination plan).

An overview of the major study components is outlined below; more detailed information on the sampling plans and methods for each component may be found in the appendices.

(1) Site-specific study of carbon sinks and fluxes in representative vegetation communities (Part A in Figure 1; Appendices A and B). The purpose of this component is to measure surface elevation change due to carbon sequestration, GHG fluxes from the land surface and vegetation, and carbon storage in soils in representative vegetation communities at the GDS. Gaseous fluxes will also be measured at PL.

(2) Hydrologic study to measure the elevation of the water table, soil moisture content, and estimate vertical and lateral fluxes of carbon as dissolved inorganic carbon (DIC) to include GHG and dissolved organic carbon (DOC) in groundwater discharged to the ditches (Part A in Figure 1; Appendix C).

(3) Remote sensing of aboveground biomass, soil properties, and wildfire (part B in Figure 1; Appendix D). The purpose of this component is to characterize refuge wide biomass carbon stock and selected soil properties such as peat depth (using probes) and soil moisture (exploring ground penetrating radar methods). This component supports the expansion of the local level carbon balance and hydrologic measurements to a refuge and regional level. Remote sensing of biomass and soil moisture measurements will begin in GDS and include PL as feasible given time and staff.

(4) An ecosystem services assessment, model, and economic valuation (Part C in Figure 1; Appendix E). The purpose of this component is to identify ecosystem service tradeoffs given alternative management actions. This assessment will integrate information from the carbon balance measurements, hydrologic measurements, and remote sensing components with other available data to provide decision support and incorporation of management and stakeholder needs. The ecosystem services assessment will begin in GDS with the potential of incorporating all three refuges.

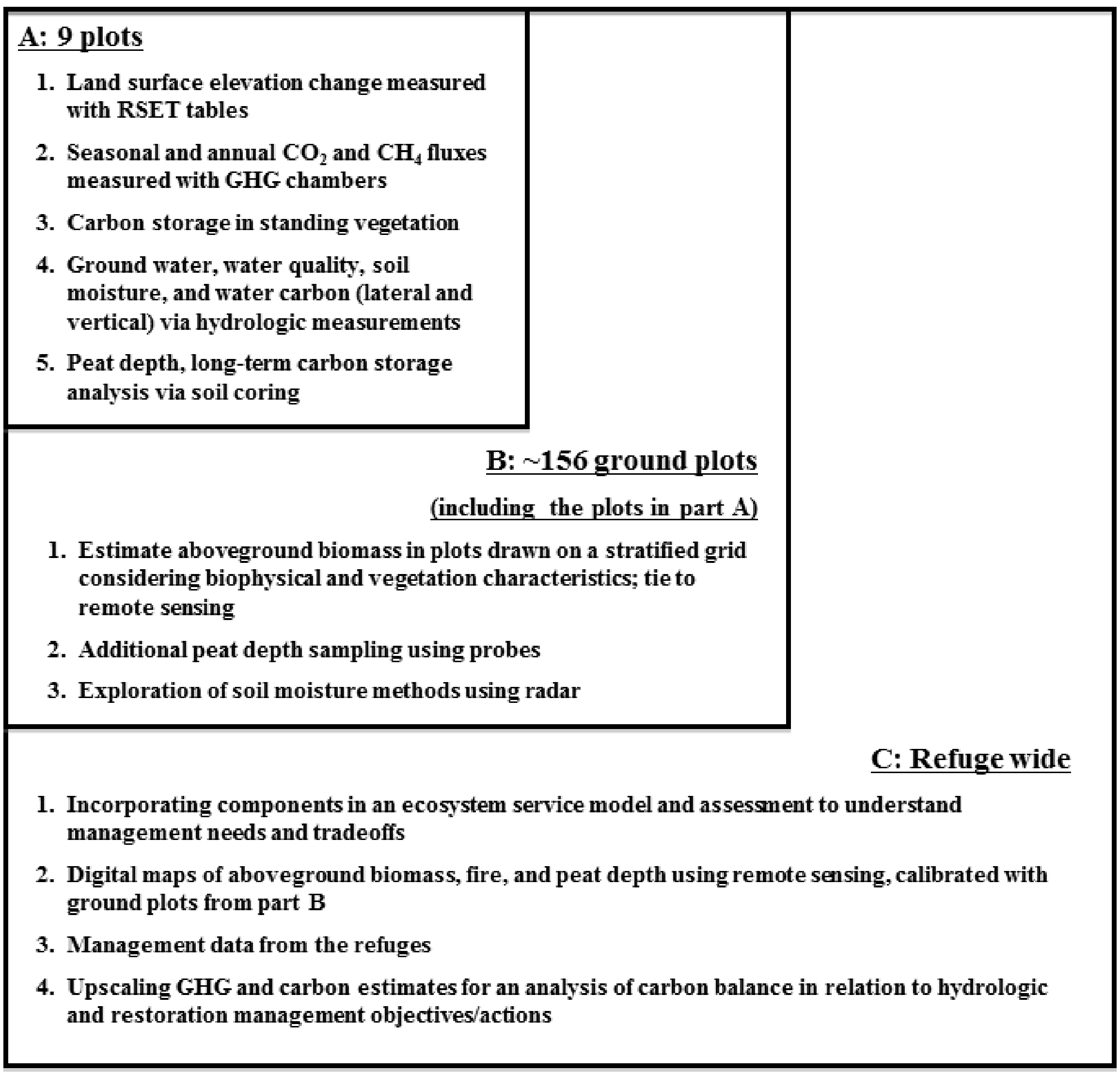

Figure 1: GDS study organization showing the relationship between components.

At the GDS, ditching has altered the hydrology of the vegetation communities so that the wetness regime and nutrient concentrations cover a range of conditions that might not be typical of those in natural vegetation community ecosystems. For this reason, the local scale study sites (Figure 1, scale A; Figure 2) will focus on three different vegetation communities, which represent the spectrum of natural to highly degraded vegetation types on the refuge. Two of the vegetation communities cover limited areas within the GDS but are among the vegetation community types desired for restoration of the swamp. The third community covers a majority of the swamp but is not a desired vegetation community type for restoration. These include (1) mature, healthy Atlantic white cedar forests (desired), (2) mature, healthy pine pocosin forests (desired), and (3) a red maple/black gum mixed community (the major, degraded, undesirable community type). All sites will be located in areas with typical water depth.

Anticipated Study Outcomes:

It is anticipated that the study will produce several products useful for refuge managers and for FWS policy and management practices, including:

- Improved understanding of how different hydrologic regimes affect the balance of carbon, GHG flux, and land surface elevation change, and how restoration could be used to increase carbon storage.
- Spatially explicit information on aboveground biomass and carbon stocks for GDS. These will be baseline data, and if repeated through time, could be used to evaluate the effects of management decisions (e.g. hydrologic management).
- New methods to monitor soil moisture and water table depth using ground penetrating radar and remote sensing to allow for more efficient hydrologic monitoring over large spatial extents.
- Baseline assessment and alternative management scenario analyses for select ecosystem services. This will contribute to the understanding of current ecosystem services, the economic and noneconomic values of those services, and the impacts of management decisions on net benefits (or tradeoffs) for the refuge, well-being of the local community, visitors, and the nation. In addition to informing management decisions on the refuge, applying an ecosystem services framework, including relative values, will support FWS headquarter goals to consider the multiple benefits provided by the refuge network and consider landscape scale environmental benefits.

General Timetable of Milestones:

This study is envisioned to have a four year time window. Table 1 below provides a general synopsis of a timetable of milestones. Each study component has a more detailed timetable provided in the appendices.

Table 1: General Timetable of Milestones

Date	Milestone	Remarks
3/2014	Initial USGS/FWS/TNC meetings at GDS and PL	
6/2014	Follow up visit to GDS	Site selection for local scale study on carbon balance and hydrology
6/2014	Onset of: • Local scale measurements (Appendices A and C) • remote sensing work (Appendix D) • ecosystem services baseline assessment with stakeholder analysis (Appendix E)	Research continues throughout study period; specific onset timing of different tasks outlined in appendices
12/2014	Draft baseline ecosystem services assessment (Appendix E)	'Final' baseline assessment may change once carbon monitoring, hydrologic, and remote sensing data are available and incorporated
12/2014	Water table wells and soil moisture probes installed (Appendices B and C)	Work begins in fall 2014. Groundwater samples collected throughout study
2015	Onset of peat coring (Appendix B)	Peat core analyses throughout 2015 and 2016.
12/2015	Draft alternative management scenario ecosystem services assessment. Includes a second stakeholder meeting in 2015.	'Final' alternative management scenario ecosystem services assessment may change once carbon monitoring, hydrologic, and remote sensing data are available and incorporated
2016-2017	Continued collection of field data, analyses, modeling and stakeholder work	Details outlined in appendices for the different components of the study
2018	Completion of analyses; updates to ecosystem services modeling; publication of reports; presentations	

<u>Appendix A</u>: In situ carbon storage and flux (Krauss and Cormier lead)

This component of the project proposes to assess in-situ carbon storage in biomass and flux in both GDS and PL. The GDS study is designed to provide an assessment of GHG fluxes and long term trends in surface elevation patterns related to antecedent and current hydrological management. The PL study is designed to assess changing GHG fluxes and surface elevation patterns during a hydrologic restoration project. All study sites (GDS and PL) in the carbon storage and flux component will yield data pertaining to surface elevation patterns, gas flux, current aboveground biomass, and rates of aboveground biomass sequestration (i.e., tree growth) for the dominant trees.

Methods for Great Dismal Swamp (GDS) National Wildlife Refuge (NWR)

The GDS study is designed to use vegetation as a proxy for previous hydrological management. We will focus on prominent end member communities at the refuge. Research plots will be established in three key vegetation types: Atlantic White Cedar (desired community), tall pine pocosin (desired community), and red maple/black gum mixed (undesired community) plots at GDS and Dismal Swamp State Park (Table 2, Figure 2). We are targeting mature, intact vegetation communities with typical water depth within each vegetation type. All treatments will be replicated three times. (3 vegetation types x 3 replicates x 1 hydrologic regime = 9 sites total).

1. Collect aboveground biomass data pertaining to downed woody debris and vegetation for current stores of C, and rates of C sequestration via dominant trees [*done in collaboration with Duberstein (see below)*].
2. Collect soil samples to a depth of up to 50 cm from 3 locations per site to analyze for bulk density, soil total C, and soil total N. [*done in collaboration with Drexler (see appendix B)*]
3. Install Rod Surface Elevation Table - Marker Horizon study plots on each site to determine surface elevation trajectories relative to management influence. We will install 1 RSET on each plot, for a total of 9 installations (3 treatments x 3 replicates). We will measure these RSETs twice annually for the first 2 years, then annually.
4. Install and train students/staff in the collection of GHG fluxes from sites using flux chambers. The goal is to relate changes in GHG fluxes to shifts in refuge hydrologic management regimes on specific wetlands. We will reduce the number of replicates by one relative to RSET measurements, and install 18 chambers at GDS (3 chambers x 3 treatments x 2 replicates). We will analyze CO_2 and CH_4 using a Los Gatos portable analyzer configured using large, 760 cm^2 flux chambers. We will periodically check gas fluxes using standard static flux chamber approaches on occasion, to include N_2O, and run all gases on our gas chromatograph (GC) at NWRC.

<u>Estimated timeline for GDS</u>. (**June 2014**) Site selection (**Sept 2014**) RSET installation and forest structural surveys. (**Nov 2014**) First RSET measurements (following required settling period), feldspar installations, flux chamber installations. (**March 2015**) Second RSET measurements, soil sampling (Drexler), and begin flux chamber measurements (incl. training students) (*gas sampling continuous from there-on*). (**Nov 2015**) Third RSET measurements. (**March 2016**)

Fourth RSET measurements. (**Nov 2016**) Fifth RSET measurements (*RSET measurements annually from there-on*).

Table 2. Locations of the proposed sites for USGS In situ carbon storage and flux study at GDS.

N	**W**	**Description**	**C cycle Site**
36 32.946	76 27.356	cedar north of Corapeake Road	cedar 1, 2
36 40.472	76 27.043	cedar south of Camp Road	cedar 3
36 43.317	76 29.784	Hudnell pocosin, pine area with some maple canopy	pocosin 1
36 33.346	76 25.523	C2 pocosin	pocosin 2
36 32.855	76 25.930	C1 pocosin, across ditch; SE corner of C1	pocosin 3
36 29.893	76 28.788	County Line Road red maple	maple 1
36 30.302	76 29.894	Wayerhauser Road red maple	maple 2
36 36.713	76 31.420	red maple east side of West Road	maple 3

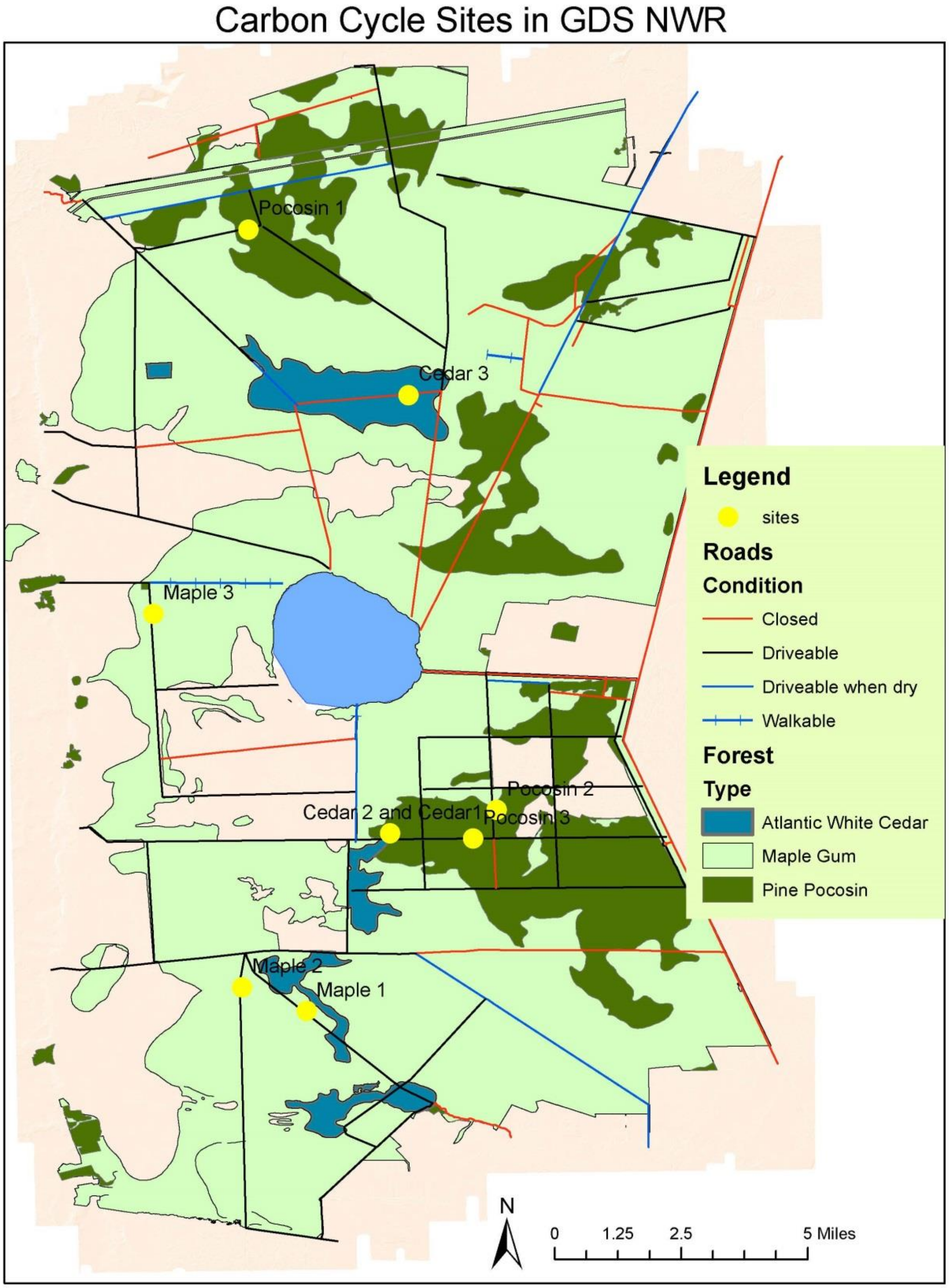

Figure 2. Study sites for in situ carbon storage and flux study at GDS. There are three study sites in each vegetation type: Atlantic White Cedar, Tall Pine Pocosin and Red Maple/Black Gum mixed.

Methods for Pocosin Lakes (PL) National Wildlife Refuge (NWR)

The Nature Conservancy (TNC) and the Fish and Wildlife Service (FWS) are developing a project in PL NWR that will determine whether hydrologic restoration on pocosin soils will induce a reduction in GHG emissions (Figure 3). This demonstration project will use peatland rewetting as a restoration practice, and be used to inform the use of the practice elsewhere to promote carbon sequestration. The USGS will estimate in-situ carbon storage in biomass and flux to assess changing GHG fluxes and surface elevation patterns during the hydrologic restoration project. This study could be complementary to the research in GDS (described above) by directly measuring the effects of hydrologic restoration on carbon storage.

FWS is planning to install water control infrastructure for hydrological restoration of 1,325 acres refuge in the Clayton blocks area (Figure 4). This effort will entail new dike/levee construction along the west and southern boundary of a combined four blocks and installation of two new water control structures.

The USGS plans to establish 4 field plots under two contrasting hydrological treatments, one hydrological treatment will receive hydrological restoration and the other hydrological treatment will not. Figures 3 and 4 shows the approximate locations of the proposed USGS study sites, and Table 3 lists the GPS coordinates. Study sites will be located within the area of hydrological restoration (wet, Block C14) and a nearby control (dry, Block D16). Study sites are along an elevation and soil moisture gradient, and the standing forest structure in plots will be surveyed. This will involve tagging trees, measuring DBH, and assessing stem density within plots. If marsh is included, we will assess standing biomass of grasses or ferns. We will conduct initial surveys, and perhaps a re-survey at a 3-5 year interval. Monitoring is proposed pre- and post-construction to determine the effects of peat rewetting on GHG emissions from these sites.

1. Collect soil samples to a depth of up to 50 cm from 3 locations per site to analyze for bulk density, soil total C, and soil total N.

2. Install Rod Surface Elevation Table - Marker Horizon study plots on each site to determine surface elevation trajectories relative to hydrologic influence. We will install 1 RSET on each plot, for a total of 6 installations (2 treatments x 3 replicates). We will re-measure these RSETs twice annually for the first 2 years, then annually.

3. Install and train students/staff in the collection of GHG fluxes from plots using static flux chambers. The goal is to relate changes in GHG fluxes to shifts in hydrologic regimes. We will install 16 chambers at PL (4 chambers x 2 treatments x 2 replicates). We will analyze CO_2, CH_4, and N_2O on our gas chromatograph (GC) at NWRC. TNC will either conduct the monthly GHG measurements themselves, or find the funding to hire a student or technician who can do the sampling.

4. Install 4 In-situ water level wells with recorders (2 treatments x 2 replicates). [*Note: the request was for 8 water wells and recorders per treatment, but NWRC will not be able to handle that full request.*]

5. Collect aboveground biomass data pertaining to downed woody debris and vegetation for current stores of C, and rates of C sequestration via dominant trees [*done in collaboration with Duberstein (see A.5 below)*].

Estimated timeline for PLNWR Installation of the road and water control structures is roughly planned for March –June 2015 and may continue through spring of 2016. We would need to install and begin monitoring the flux chambers and SETs prior to the installation of the proposed infrastructure. (**Jan/Feb 2015**) Site selection, RSET installation, soil sampling, water level recorder installation. (**March 2015**) First RSET measurements, feldspar installations, and flux chamber installations. (**Nov 2015**) Second RSET measurements, forest structural surveys (**May 2015**, begin flux chamber measurements (incl. training students) (*gas sampling continuous from there-on*). (**March 2016**) Third RSET measurements. **(Nov 2016)** Fourth RSET measurements (*RSET measurements annually from there-on*).

Table 3. Locations of the proposed sites for USGS In situ carbon storage and flux study at PL.

	N	W		
waypoint 016	35 39' 00.0"	76 29' 01.6"	Pocosin Lakes NWR, C13 dry, higher elevation	Restored 1
waypoint 021	35 38' 22.2"	76 29' 51.5"	Pocosin Lakes NWR, C14 near end of longest Geoboy trail	Restored 2
waypoint 024	35 37' 25.6"	76 28' 27.4"	Pocosin Lakes NWR, D16 drained control block	Control 1 and 2 nearby

Pocosin Lakes NWR Carbon Cycle Sites

Figure 3. Proposed sites for USGS In situ carbon storage and flux study at PL NWR.

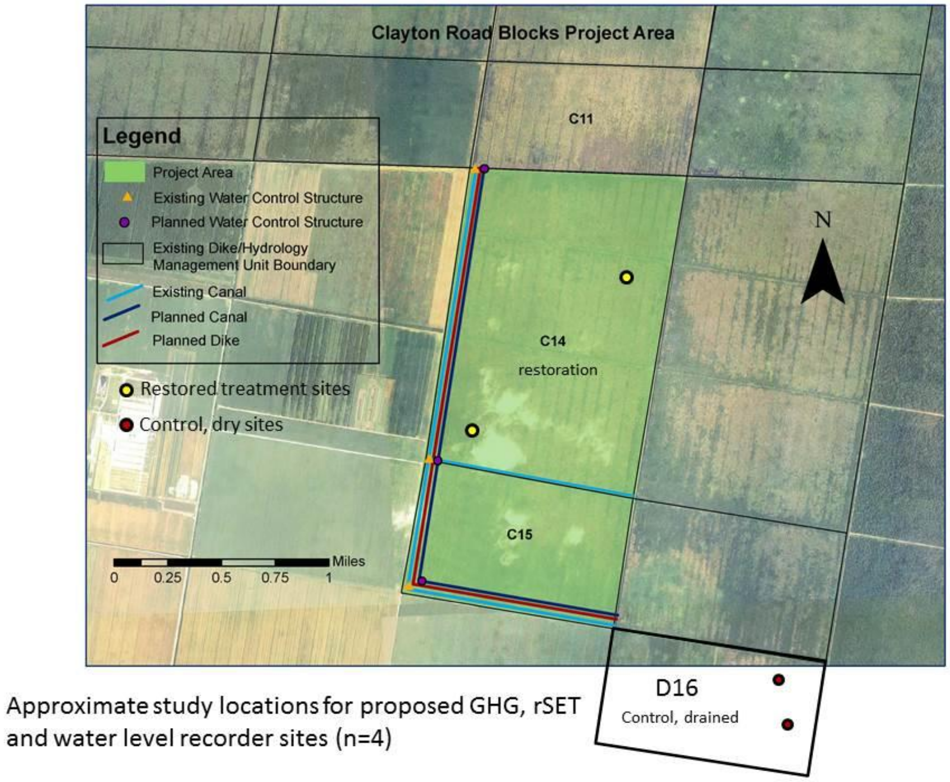

Figure 4. Proposed sites for USGS in situ carbon storage and flux study at PL NWR. There are two study sites in each treatment: two sites in the C14 block selected for restoration and two sites in the D16 block that is to remain drained and unaltered.

C storage assessment within standing vegetation (Duberstein lead)

Aboveground C storage as standing vegetation will be assessed at the nine study sites within GDS and the four study sites within PL. This work is subset of the effort led by Krauss and Cormier, and is done by an academic partner (Duberstein).

Two levels of assessment will be used: 1) current standing stocks of trees, shrubs, and downed woody debris within 3.2 m fixed radius (100 m^2) plots, and 2) rates of carbon sequestration via growth of co-dominant trees within 20 x 25 m (500 m^2) plots.

1. Current standing stocks of C will be determined using 100 m^2 (3.2 m radius) plots. Assessment will include: woody debris, soil litter and duff depths, peat depths, herbaceous vegetation percent cover, shrub composition, and tree composition. Methods are compatible with those of Hawbaker [*see Appendix D*], making datasets usable for each task.

   Once plot center is established and measured using the Trimble GPS, three (10 m) woody debris transects are laid out at azimuths of 60°, 180°, and 320°. Fine woody debris is assessed along each transect from the ground level to a height of 2 m above the ground. Tallies of 1-hr fuels are counted between 0 – 2.5 m, and tallies of 10-hr fuels are counted between 0 – 5m. Coarse woody debris is measured (diameter, using a large caliper) and assessed for its decomposition class between 0 – 10 m. Decomposition classes range 0 – 5, with 0 as recently fallen and 5 as touching the ground at all points, yet not decomposed to the point where half of the tree is undiscernible from the soil litter. Depths of litter layer (nearest cm) and duff layer (nearest cm), and depth of peat layer (nearest cm) are collected at the 2.5 m and 5.0 m points along each transect.

   Shrubs are identified and measured (diameter at root collar = DRC) within the 120° area (of two adjacent transects) that is representative of the area; the shrub survey area is identified immediately after transects have been laid out, and care is taken to leave it relatively undisturbed. Shrubs are defined as non-vine woods stems < 30 cm tall with diameter at root collar as 2.5 cm > DRC > 0.5 cm.

   Trees are identified and measured (diameter at breast height = DBH) to the nearest 0.1 cm. If the tree is dead, it is still measured if the angle at which it leans is < 45° from the ground (else it is coarse woody debris if it is less than 2 m from the ground). The heights of some trees will be measured, as determined using the wedge prism approach incorporated into the hypsometer: if DBH ≥ distance displayed under the ‘distance’ function, then the height of that tree is measured using the hypsometer.

2. Rates of C sequestration via growth of the dominant trees will be determined using 500 m^2 (20 x 25 m) plots. These larger plots will include the area captured in the 100 m^2 survey.

   Pine pocosins within GDS have dominant trees (usually pond or loblolly pine) spaced out in a fashion whereby a continuous upper canopy does not exist, but instead has a continuous sub-canopy consisting mostly of saplings, shrubs, and vines, with the occasional large pine tree of much higher stature. Small plots (100m^2) are impractical if estimates of basal area on a per-hectare basis are desired, due to the large differences inherent in such a small area (100m^2 plots typically capture between 0 – 3 dominant trees). While the 100m^2 plots are desirable for collecting a large number (e.g., 100 – 200) of randomly placed plots over a large spatial resolution [*see Hawbaker*], the vegetation plots monitored in concert with the in situ carbon storage and flux component of the study will be relatively few (1 - 2 per site) and carefully located near RSET and gas flux locations [see Krauss and Cormier] and peat extraction sites [see Drexler]; not random at all. Close proximity between vegetation plots and measured environmental conditions helps assure continuity of datasets. We seek to link growth of the dominant trees to environmental conditions, so a larger area (500 m^2) is needed to adequately incorporate the structural diversity of trees within all community types. The resulting data will yield more accurate per-hectare basal area measurements, growth rates, and death rates of the dominant trees, and allow for correlation with the environmental monitoring data being collected on site (via e.g., RSETs, water level recorders, peat cores, gas flux chambers).

All trees ≥ 10 cm DBH will be tagged with an aluminum identifier fixed on an aluminum nail, situated in a fashion that hangs the bottom of the tag 1.4 m above the ground for trees growing straight up, or 1.4 m along the bole of the trees for trees that have a considerable lean. Placement of the tag corresponds allows for annual measurement in the same spot over successive years, and complies with standard forestry survey practices. Trees are identified to species (or lowest possible taxonomic unit, e.g., *Fraxinus* for all ash species) and measured to the nearest 0.1 cm. Several trees within each 500 m^2 plot will be outfitted with dendrometer bands to obtain greater temporal resolution growth increments (e.g., seasonal) with greater accuracy. Data from dendrometer bands will likely increase the strength of the correlation between growth and hydrologic conditions at GDS [*see Appendix C: Speiran*] and PL [*see Appendix A: Krauss and Cormier*], should they exist at GDS and/or PL.

Estimated timeline for standing vegetation surveys: Forest structure surveys for GDS (September 2014). Forest structure surveys for PL (May 2015).

<u>Appendix B</u>: C storage in soils (Drexler lead)

The goal of this part of the study is to determine the amount of carbon being stored in the organic peat soils of the Great Dismal Swamp. Because carbon storage is expected to differ depending on plant community type, we will collect cores in each of the three replicate sites in the three different vegetation communities being studied at the GDS: (1) maple/gum forest, (2) tall pocosin, and (3) Atlantic white cedar forest (Table 2, Figure 2). Cores will also be collected in undrained and relatively undisturbed Atlantic white cedar sites outside the refuge in order to estimate how peat has changed subsequent to drainage and hydrologic management in GDS. This soil coring study requires data on water table and soil moisture data being collected as part of the hydrologic component described in Appendix C.

1. Establish peat coring sites in each of the 9 study sites chosen by the carbon cycle group.
2. Collect one peat core in each site as well as additional cores in relatively undisturbed Atlantic white cedar swamps outside the refuge.
3. Section cores into 2-cm sections and analyze peat for bulk density, total organic matter, total N, total organic C, lignin components, and ^{210}Pb and ^{137}Cs for dating purposes.

<u>Estimated timeline for GDS work</u>. **August 2014:** Site selection and choose water table well locations and potential soil moisture probe locations. **February/March 2015**: Collect peat cores in each study site. **August 2015:** Complete initial processing of peat cores. **September 2015**: Submit core samples for ^{210}Pb and ^{137}Cs dating and carbon analyses. **March 2016:** Analyze chemical data using statistical methods. **October 2016:** Begin report writing. **August 2017:** Complete report on results.

Appendix C: Groundwater Hydrology, Quality, and Carbon Export (Speiran lead)

Background

Because the hydrologic characteristics of any site control much of the carbon incorporation into biomass, the release of carbon from the biomass, and the transport of carbon through the system, understanding the hydrologic characteristics and groundwater quality/geochemistry of the site can be important for interpreting monitoring results and quantifying the bulk of carbon transport. Additionally, hydrologic characteristics help control the biological community composition and health. The pocosin and Atlantic white cedar forest communities selected for study are nutrient poor wetlands characterized as ombrotrophic because precipitation typically is their sole source of water and nutrients. Although groundwater commonly remains near land surface in these communities throughout the year, standing water is seldom. The nutrient and hydrologic characteristics of the maple/gum communities at GDS is uncertain and might be similar to the pocosin and cedar communities.

At the GDS, precipitation rapidly recharges the groundwater and laterally flows through the upper peat to discharge to nearby ditches; some water can flow vertically into the deeper part of the peat. Unlike in similar forest communities in natural systems, groundwater flows rapidly because the presence of the ditches increase hydraulic gradients and decrease the distance between recharge and discharge areas or sinks and because the ditches are the major water sinks. These flow paths and the rapid characteristics of the flow can control carbon transformation, transport, and discharge. Where groundwater flows nearly vertically, dissolved oxygen and other electron acceptors are transported to greater depths than where flow is more horizontal. Thus, the more rapid decomposition of carbon compounds that produce greater amounts of carbon dioxide and dissolved organic carbon (DOC) in the oxygenated environment can extend to greater depths. When dissolved oxygen first becomes depleted, carbon decomposition is slowed and carbon dioxide and probably DOC production decrease. The presence of electron acceptors other than organic carbon (nitrate, oxidized iron, and sulfate) in this part of the system will prevent methane production from occurring in appreciable amounts until these constituents also are depleted even deeper into the system. Because the flux of dissolved constituents by advection dominates over diffusion, vertical groundwater flow transports the carbon breakdown product deeper and also limits the diffusion of carbon dioxide and methane into the soil atmosphere and eventually to land surface. Where lateral groundwater flow is rapid in the upper peat, effects of diffusion also are limited so that a large part of the carbon dioxide and methane might be transported and discharge to the ditches in the water with the DOC. This combination of processes might make gas discharge to the atmosphere different above different parts of the groundwater flow system. Under this scenario, discharge of GHGs to the surface might increase toward the ditches. The amount of carbon discharge through the groundwater to the ditches relative to discharge to the atmosphere is uncertain but might approach or exceed discharge to the atmosphere above the land surface.

Component Objectives

The groundwater study component has three main objectives: (1) to provide hydrologic information to support the other study components, (2) to attempt to quantify the carbon export through the groundwater to the ditches, and (3) to provide refuge staff with hydrologic and nutrient targets for managing pocosins to meet habitat and carbon sequestration goals at the GDS, PL, and AR refuges.

Methods

The groundwater component will focus on the nine sites in three vegetation community settings (Table 2, Figure 2). Data collection will include groundwater levels, soil moisture, precipitation, and groundwater samples.

Groundwater levels

Because each study site does not cover an entire block and might not be near a ditch, water table wells will be constructed around and in the center of each site. Water levels will be measured periodically (every one to two months) in all wells and continuously (15-minute intervals) using pressure transducers in the well near the center of each site. Data collection platforms (DCPs) will be used to store continuous groundwater level, soil moisture, and precipitation data collected at each of the main sites and transmit the data through the USGS real time network. Groundwater levels will be used (1) to evaluate the hydrology of each site, (2) in the analysis for the carbon standing stocks and monitoring and the carbon storage in soils components of the study, (3) to calibrate remotely sensed images for mapping the elevation of the water table across the refuge, and (4) to develop hydrologic targets for managing water levels in ditches based on conditions in the natural setting.

Soil Moisture

Although groundwater levels are the most commonly measured hydrologic characteristic, knowledge of soil moisture also can be critical because soil moisture affects plant communities, carbon decomposition, and the risk of severe fire. Soil moisture will be monitored continuously (15-minute intervals) near land surface near the well having continuously measured water levels at all nine sites. At one selected site, a vertical profile of the soil moisture also will be monitored. Monitored depths will be selected to best represent the soil moisture profile as affected by vertical changes in peat characteristics and groundwater level fluctuations. Based on result of this monitoring, this type of monitoring might be expanded to additional sites. Changes in soil moisture will be will be related to changes in groundwater levels (1) to evaluate the hydrology of each of the sites, (2) in the analysis for the carbon standing stocks and monitoring and the carbon storage in soils components of the study, (3) to calibrate remotely sensed images for mapping the soil moisture content across the refuge, and (4) to develop hydrologic targets for managing water levels in ditches based on conditions in the natural setting.

Precipitation

Precipitation will be monitored continuously (15-minute intervals) at one of the sites in each of the three settings if a site can be identified where interference from the tree canopy likely would be minimal. Precipitation will help in the assessment of groundwater levels and soil moisture (1) to evaluate the hydrology of each site, (2) in the analysis for the carbon standing stocks and monitoring and the carbon storage in soils components of the study, and (3) to develop hydrologic targets for managing water levels in ditches based on conditions in the natural setting.

Groundwater Samples

Groundwater samples will be collected from selected wells that are part of the initial network and additional wells and piezometers constructed specifically for sample collection. Where appropriate, clustered wells/piezometers will be constructed open to different depths. Samples will be analyzed in the field for water temperature, specific conductance, dissolved oxygen concentration, and pH. Samples will be analyzed in laboratories for major ions (includes sulfate), dissolved nutrients, stable isotopes of water, dissolved gases (including carbon dioxide and methane), dissolved organic carbon, and possibly groundwater age. Samples will be collected quarterly; all samples will not be analyzed for all analytes.

The water quality analyses will meet several needs: (1) improve the understanding of the hydrology, (2) helping to understand where vertically and laterally peat decomposes at different rates in different environments, (3) comparison of nutrient concentrations in natural and GDS pocosins to help establish water and nutrient management goals, and (4) quantifying carbon transported through the groundwater and discharged to the ditches. Many water quality constituents/ characteristics (major ions, stable isotopes, etc.) serve as tracers to help evaluate groundwater flow paths and could be important in the analysis for different study components. The quality of water in wells adjacent to the ditches will be used to calculate carbon discharged to the ditches where discharge to seepage collectors cannot be collected.

<u>Appendix D</u>: Biomass and Soil Moisture Monitoring (Hawbaker lead)

Baseline data are needed to characterize spatial variability in current vegetation biomass and the hydrologic conditions influencing biomass production across the refuges. With repeat measurements, these data can also be compared with future carbon stocks and hydrologic conditions to assess the impacts of management actions. Remote sensing is the only feasible approach to produce such spatially explicit data with repeated measurements. We will conduct a field campaign to collect the necessary data to map aboveground biomass using LiDAR; this approach has been demonstrated to work in a variety of ecosystems globally. We will also work with other collaborators to research new methods to link soil moisture and water table depths (collected at wells and using ground penetrating radar) to airborne and space borne radar data. This work will initially focus on GDS NWR and will be extended to PLNWR, if time and resources allow.

Methods

We will establish a network of field plots at which we will measure relevant characteristics of vegetation needed to estimate biomass (Figure 5). These data will be used as response variables in regressions with LiDAR summary statistics (e.g. average pulse height; Hawbaker et al. 2009). The regressions will be specific to vegetation types (e.g. pocosin or maple-gum) and therefore, selection of field plot locations will be based on a stratified sampling design, with the goal of having 30-60 plots per vegetation type.

Selection of plot locations

At GDS NWR, we limited our sampling to the 4 dominant wetland vegetation types in the Forest Community Data layer provided by FWS: (1) Atlantic White Cedar, (2) Cypress Gum, (3) Maple Gum, and (4) Pine Pocosin. Within each vegetation type we selected plots were separated from other plots by 500 m; were more than 50 m from roads and ditches, but less than 250 m from roads/ditches to minimize travel times. This resulted in a total of 156 plot locations (only 37 locations could be found for Atlantic White Cedar).

LiDAR and Radar data:

UAV borneA number of LiDAR datasets will exist for GDS NWR and PL NWR by the time we start collecting field data. For Virginia (GDS NWR), we will have data from 2010 for Suffolk City (County) with 1 pulse/m^2; 2012 data with 2 pulses/m^2 for part of GDS NWR; and 2013 data with 2 pulse/m^2 for Chesapeake City (County). For North Carolina (GDS NWR and PL NWR) we will have 2013 data with density of 2 pulses/m^2. A number of airborne and space borne radar datasets are available for the GDS and PL NWR. We will access each dataset and gather the most relevant ones for mapping soil moisture and water table depth (lead by GMU PhD student). We will also explore the use of ground penetrating radar to more efficiently measure water table depth and peat depth in the field.

Field data:

Field plots will have a fixed radius of 3.2 m, corresponding to a plot area of 100 m^2 which will match the resolution at which the LiDAR data will be summarized. Within each plot, we will record tree (woody stems with DBH ≥ 1”) species and diameter. Tree height will be measured for a subset of trees in each plot. We will calculate tree biomass using the equations in Jenkins et al. (2003). We will measure the height and percent cover of shrub and herbaceous vegetation in each plot and will also estimate their biomass using allometric equations. Downed-dead wood will be measured along transects 3 at each plot, following methods in Brown (1974). Peat depth measurements will be taken at 3 randomly located locations within each plot.

Data analysis

The LiDAR and field data will be analyzed to generate wall-to-wall maps of tree biomass for GDS NWR during the fall of 2014 using methods similar to Hawbaker et al. (2009). We will also explore the ability of LiDAR to estimate biomass in understory layers, something that has historically been challenging in other ecosystems. We anticipate this work will result in a journal article publication. We will also work with George Mason University PhD student Laurel Gutenberg to analyze radar data in relation to our field measured biomass values, soil moisture, and water table depth. We anticipate that her work will result in one or more journal articles.

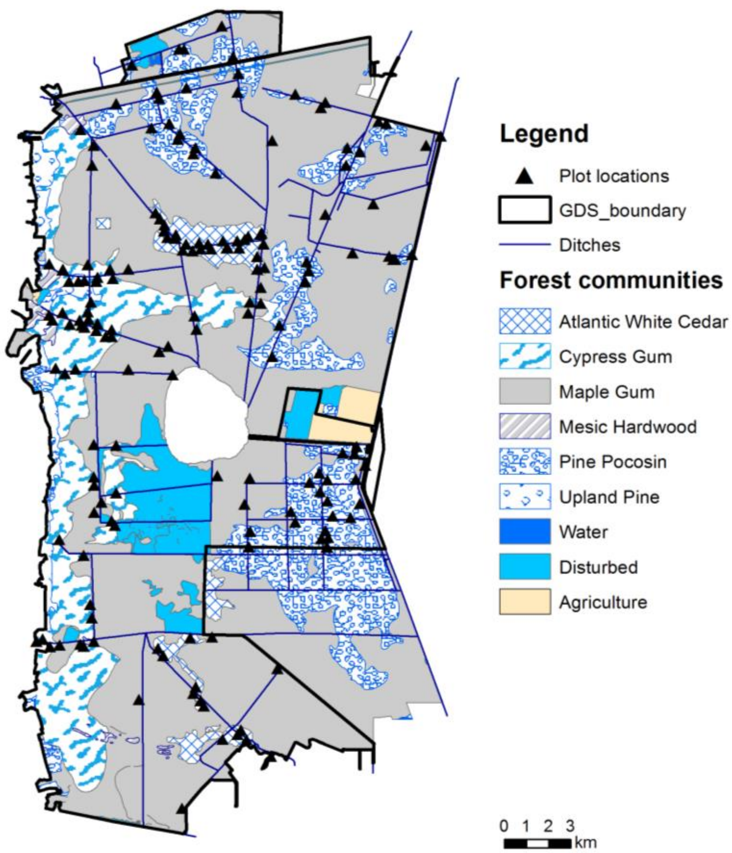

Figure 5. Draft map of locations for vegetation/biomass sampling at GDS NWR. The sampling design may be revised with updated GIS data to exclude recently harvested and burned areas.

<u>Appendix E</u>: Ecosystem Services Assessment, Model, and Valuation (Hogan and Pindilli lead)

Ecosystem service quantification and valuation is important to help identify the service tradeoffs given alternative management actions and to address a growing demand for more sophisticated analysis of the social and economic consequences of biophysical land management decisions. Understanding the complex social and ecological relationships and the tradeoffs will help support more informed decision-making. For example, an ecosystem service valuation model applied to FWS NWRs (Arrowwood, Blackwater, Okefenokee, and Sevilleta & Bosque del Apache) suggested that refuge size and the socio-demographic characteristics of the surrounding region are important determinates of the estimated per acre value of wetlands in providing ecosystem services (services included C storage, storm protection, water quality, and commercial fish habitat; Patton et al., 2012).

Methods

The ecosystem services assessment will estimate the quantity, quality, and value of select ecosystem services in the GDS refuge. The assessment process includes an estimation of the baseline (current) condition of ecosystem services as well as an analysis of potential (future) changes to the condition of ecosystem services as a result of alternative management decisions. Each step of the ecosystem services assessment includes estimation of the quantity and quality of services – or the biophysical endpoints, identification of the beneficiaries, and valuation of the services to the beneficiaries. This effort includes significant stakeholder input on the prioritization of selected services and on the development of alternative management scenarios. There are a number of steps to conduct an ecosystem service assessment that are well documented and aim to provide consistent, objective results. The ecosystem services assessment will be done using the using the established framework with the following high level procedures:

1. **Baseline Ecosystem Assessment** – this is the initial phase which includes GIS landscape analysis of the refuge, literature review to identify candidate ecosystem services, stakeholder and management meetings to select ecosystem services, area demographic analysis, modeling and quantification of ecosystem service biophysical endpoints, beneficiaries, and values.
2. **Scenario Development** – to inform decisions and provide better information on potential future conditions, scenarios will be developed that include alternative management decisions and or other priority changes (e.g., climate change) to estimate the impacts on ecosystem services. Scenario based analysis is an approach to provide additional information to managers and stakeholders on the effects of their actions and improve decision-making. Scenario development will be conducted in coordination with refuge managers and stakeholders to ensure scenarios are realistic and provide useful information.
3. **Scenario Analysis** – the last step in the assessment is to evaluate the effects of the scenarios on the ecosystem service assessment model inputs used for baseline development, to run the model given these new variables, and provide the quantification of ecosystem service biophysical endpoints, beneficiaries, and values under each of the new scenario conditions.

This work will be documented in scientific journals or other publications. Additionally, the results will likely be presented in multiple forums and the project team will work closely with the FWS at headquarters and managers at the refuges to provide continuous results. The following sections provide greater detail for each of the above high level procedures.

1. Baseline Ecosystem Service Assessment

The baseline ecosystem service assessment has a number of steps and analyses to identify, quantify, and value the ecosystem services in the GDS refuge; detail is provided below.

a. **GIS Landscape Analysis** – Important components include available data on land use/land cover (LULC), plant communities, soils, aerial photography, geology, hydrology, coastal wetland restoration activities (with dates), fire activity (either by nature or by management), what areas are dry (ditched), and what areas are being or recently have been reflooded.

b. **Literature Review** – An extensive literature review of the GDS and region will be conducted to determine what candidate ecosystem services the refuge may be supplying, whom may be benefiting, other research that has previously been conducted on the GDS that is relevant, other ecosystem service assessment of wetlands and/or refuges that are relevant, valuation of benefits with the potential for benefits transfer, and previous impacts of degraded ecosystem services in the region and those costs (such as property loss due to fire). Carbon sequestration is a priority ecosystem service for consideration; additional services that may be considered are freshwater provision, endangered species (red wolf and others), recreation, and disturbance prevention.

c. **Ecosystem Services Selection Stakeholder Meeting** – The project team conducted a stakeholder meeting on June 11, 2014 at the Russell Memorial Library in Chesapeake, VA to identify a list of 'priority' services for assessment. There were 23 meeting participants from a range of interests including the cities of Chesapeake and Suffolk, Virginia, states of Virginia and North Carolina agencies, federal agencies, national refuge and environmental interest groups, universities, and local environmental nonprofit agencies.

   The project team provided a briefing on what ecosystem services are, the framework for considering ecosystem services, the approach to conduct an ecosystem service assessment, and the overall ecosystem service assessment project timeline. The briefing continued with a menu of ecosystem services, highlighting those services that the project team preliminarily considered relevant to the GDS. The briefing included a detailed suite of slides on relevant ecosystem services including the pathway from basic ecological function, to ecological benefit, to social or economic benefit.

   Table 4 shows the ecosystem services discussed in the meeting with those identified as priority services by the meeting participants ranked highest. This list will be used to inform which ecosystem services the USGS assesses. It is important to note that the feasibility of evaluating the ecological and economic benefits of any of the services within the project timeline and scope will also be factors in the services which are assessed

Table 4: Ecosystem Services discussed and prioritized in the initial stakeholder meeting

Ecosystem Service	Number of Votes	Rank
Biodiversity	20	1
Wildlife Viewing	12	2
Education	7	3
Nutrient Cycling	6	4
Flood Protection	6	5
Carbon Sequestration	5	6
Fire Mitigation	5	7
Recreation (biking, hiking, boating)	4	8
Cultural Heritage	0	9
Recreational Hunting	0	10
Aesthetic	0	11
Recreational Fishing	0	12
Timber	0	13
Fresh Drinking Water	0	14

d. **Demographic Analysis** – demographic statistics for the area surrounding the refuge will be identified (secondary source, not primary) and evaluated along with visitation rates and other possible factors that indicate whom the beneficiaries of the ecosystem services are and the magnitude of benefits to the population.

e. **Modeling and Quantification of Ecosystem Service Biophysical Endpoints** – Based on the ecosystem services that were selected, the ecosystem services assessment methods and model will be determined. A recent USGS study assessed numerous methods and tools that quantify and value ecosystem services for their usefulness to BLM decision-making (Bagstad et al., 2012). Based on this and other assessments, for our application, our initial recommendation is to use the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST model). The InVEST model was developed by The Natural Capital Project (http://www.naturalcapitalproject.org/models/models.html) and offers a set of ecosystem service models designed to both map and value tradeoffs between multiple ecosystem services relevant to FWS NWR needs. These services include C storage and sequestration, freshwater supply, biodiversity (habitat provision), nutrient removal or dispersion, recreation, fishery support and disturbance prevention. The model largely relies on the categorization of LU/LC types, precipitation and hydrologic data, and refuge visitation rates; we anticipate that the FWS will be able to provide input on many of these parameters [need FWS participation]. Final determination of the precise methods and model will be based on the ecosystem services that are chosen and the required analyses. The ecosystem services model will be developed and populated using available data, monitoring data developed as part of this project, and lessons learned from other relevant analyses. The monitoring will provide site specific information on actual carbon sequestration and hydrology. As this information becomes available, it will be incorporated into the model to improve the ecosystem service analysis as well as provide direct information for adaptively managing the NWRs.

f. **Valuation** – Valuation of the ecosystem services will be conducted using economic techniques for non-market goods; primary studies or surveys of willingness-to-pay are not within the scope of this analysis. Techniques employed may include benefit transfer methods, cost- or price-based derivation, and health impacts avoided. InVest includes some valuation modules and will be used to the extent feasible and appropriate.

2. Scenario Development

Developing realistic scenarios for analysis of the 'what-ifs' associated with management decisions or uncontrollable external factors (such as climate change) provide information to refuge managers on the potential impacts of their actions, how those actions might affect surrounding communities, and on approaches to best enhance desired outcomes or mitigate undesired outcomes. It is important that scenarios reflect reality to provide meaningful information and a conventional approach for scenario development is to elicit stakeholder and management input. The steps for developing scenarios for the GDS ecosystem service assessment are described below.

a. **Strawman Scenario Development** – Based on initial interactions with refuge management, stakeholders, and the literature, the project team will develop a set of strawman development scenarios. These will be used to initiate discussions on priorities and details of scenarios with stakeholders.

b. **Scenario Development Stakeholder Meeting** – To develop the most important alternative management scenarios for the refuge managers and the area community, the project team will conduct a stakeholder meeting in, or close to, the GDS refuge. The purpose of the meeting will be to identify priority management alternatives and the expected impacts of those actions on the refuge and the surrounding communities. The project team will endeavor to engage the same stakeholders as participate in the ecosystem service identification meeting, adding decision-makers as appropriate. Possible scenarios could include a climate change scenario whereby temperatures are higher in the refuge or a scenario of alternative water control over the ditches.

   The team will coordinate this meeting midway through the project. The meeting will include a presentation of the results of the baseline assessment, a presentation of strawman scenarios and a facilitated prioritization activity to get the stakeholders to 'vote' on and discuss their justifications for choosing management scenarios.

3. Scenario Analysis

The final phase of the ecosystem service assessment is to analyze the alternative management scenarios. This provides a snapshot of potential future quantity, quality, and value of ecosystem services in the GDS and is intended to support decision-making. A description is provided below.

a. **Scenario-Based Analysis** - The scenarios will be translated into biophysical impacts on the refuges in the ecosystem services model. The model will be run under these new conditions and will provide the biophysical and economic impacts of select alternative management decisions. It is anticipated that a third stakeholder meeting with a presentation of the final results will be appropriate at the project culmination.

Estimated timeline: **(June 2014**) Initial stakeholder meeting near GDS. (**Summer and Fall 2014**) development. (**Winter 2014-2015**) Scenario development stakeholder meeting. (**2015**) Scenario analysis. Incorporation of site specific carbon information will be done as data becomes available. A presentation of the final results will be provided at the project culmination.

Appendix F: Coordination and Management

This project is collaborative in nature and involves scientists, technical staff, managers, and students from USGS, FWS, the three NWRs, TNC, and academia. Study management will be achieved through:

- A coordination team comprised of FWS, USGS, NWR managers, TNC, and the project lead to provide oversight, general organization, agency communication and funding decisions.
- Interim reports twice a year (targeted for the end of July and the end of January).
- A project review meeting will be conducted each December during the project period. All technical components will be reviewed, and progress will be reported and communicated with all participants of the study.

Ecosystem Services Assessment and Carbon Monitoring Team	
Coordination Team	Potential coordination team members include FWS (John Schmerfeld, Sara Ward), USGS (Zhiliang Zhu, Brad Reed, Dianna Hogan), NWR managers (Chris Lowie, Howard Phillips), and TNC (Christine Pickens, Chuck Peoples)
Dianna Hogan	Project lead; provides technical communications with all participants of the project. In addition, ecosystem services analysis, model development, and field research
Ken Krauss, Nicole Cormier, Jamie Duberstein, Courtney Lee, Rebecca Moss	Field research - carbon storage and flux
Judy Drexler; lab assistant	Field research - carbon storage in soils
Gary Sperian	Hydrologic measurements to assess lateral flux and efflux of carbon
Todd Hawbaker, Zhong Lu	Biomass and soil moisture measurements and fire characterization
Emily Pindilli	Economics analysis; model development
Sue Hazlett	GIS landscape analysis; model development
Kim Angeli and Doug Wheeler	Advanced Systems Center (ASC) remote sensing scientists. Temporal imagery to look at before/after effects of management actions via use of Imagery Derived Products (IDPs)
FWS refuge staff Fred Wurster; others as deemed appropriate by FWS	Partnerships; advice on monitoring and analyses; data sharing
Laurel Gutenberg, Marek Salanski, Chris Wright, Christina Musser, Tim Larson	Student interns: field work, model development

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